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BIOLOGICAL MODELS
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ILLUSTRATIONS

PREFACE

THE use of models in teaching cannot in itself claim originality, and all biologists are familiar with the beautiful and expensive commercial models, used in university laboratories for the better comprehension of external appearance and internal arrangement of organisms. However, some of the models described in the following pages are, as far as the author is aware, original, in that they offer a new method of presenting facts, so that they can be grasped by schoolboys, whose chief difficulty is to think in three dimensions. In addition to this the use of models permits rapid revision, but it is of the utmost importance that this use should not be allowed to take the place of actual practical work or dissection.

Most of the models have been in use for several years, and time spent on their design and construction has been amply repaid by the assistance they have given to the classes which have used them.

The author is indebted to Mr. Ian Hamilton of Dauntsey's School for permission to include the description of the snake's skull, and also to Messrs. F. N. Hoggett, J. L. Lee, and D. F. Burnett, all

of Leeds Grammar School, for the sections on the artificial hotbed and embedding apparatus, the section on plaster of Paris, and the section on the modified potometer respectively. The editors of the *School Science Review* and *Biology* have kindly allowed him to reprint the substance of articles on plasticine modelling, and have also allowed him to use their blocks for illustrations.

Several models in general use have been described (e.g. the cell of Spirogyra, and the cell pressure apparatus), and no originality is claimed for them.

Mr. D. L. W. Tough has offered many helpful suggestions, and has very kindly read and corrected the proofs.

R. D. W. B.

April, 1937.

CHAPTER I

The Use of Various Types of Models

IT is perhaps obvious, but not entirely irrelevant, to say that there are three methods by which facts may be taught, by word of mouth, by visual means, such as the diagram, or better still the film, or, best of all, by actual observation of the object studied. Now of these three methods, the last is unquestionably the best, but at the same time in Biology it is, for several reasons, not always practicable. Sometimes it is not possible to obtain fresh plants and animals for students to examine and dissect; and frequently, even if fresh material is available, they cannot always understand what they see, or, what amounts to the same thing, they cannot always observe all the structures which exist, especially when using the microscope, nor can they fully grasp the changes which take place during the development of living organisms. And here another aspect of the matter presents itself; animals in particular, and to a lesser degree plants, cannot be kept fresh for an indefinite period, though Botanical material can usually be easily preserved, and as a result the student can see the structures only once or twice during dissection, and then must rely on

his memory and his own drawings, or text-book diagrams, for revision. The immediate result of this is that demonstrators quite rightly demand a high standard of drawing from their classes, and, since many students are not naturally gifted artists, much time has to be spent in acquiring a superficial skill in the art, which cannot be regarded as of paramount importance at a later period when examinations are over.

It is to bridge the gap, therefore, between the word of mouth, the film or diagram, and the actual living organism, that models of one sort or another can be used to the greatest advantage. The several ways in which these models may be used have been divided in the following chapters into two groups. These groups are not complete, but it is hoped that they will enable teachers to make further models on similar lines.

1. The first group describes the production of plastic models for use in front of a limited class in such a way that the actual formation of the model closely follows the mode of development in the living animal, plant or part thereof. Under this heading various embryological changes can readily be demonstrated. Since plastic material can easily be sectioned, it is possible to produce large-scale sections similar to those which are later to be observed under the microscope—this being of the greatest value where the young student does not prepare his own slides, as he cannot possibly do in embryology.

Frequently, however, it is desirable to have a model which can be kept, and the production of plaster of Paris casts makes it possible for members of a class to construct their own models, and thus learn much more than they would from reading a text-book in a preparation period.

2. The second group consists of a varied collection of constructional and panoramic models. The former are meant to pave the way to actual dissection, or for revision after dissection, when fresh material, or time for further dissection, is not available.

The panoramic type of model aims at the production on a small scale of prehistoric animals in their correct environment, or of animals now living in some part of the world which few English students have seen. An obvious example is the production of some prehistoric scene either Zoological, or Botanical, or a mixture of both if desired, or the reproduction of some method of fighting disease (e.g. Malaria) in which conditions are portrayed, together with the apparatus necessary for the control of the pest. This is suitable work for younger forms and usually gives a great deal of pleasure.

The last chapter describes various pieces of laboratory apparatus which have proved useful, though they cannot in any way be considered as models.

CHAPTER II

Plastic and Static Models

THE difficulty of thinking in three dimensions is probably nowhere so great as in embryology, and the additional factor of growth makes it an even more complicated problem. The demonstrations described below must be carried out in front of the class, and their chief limitation is that not more than ten or twelve people can be grouped round the demonstrator to see what is being done. However, there can be few schools with more than a dozen candidates in H.S.C. and scholarship classes, and, if numbers are larger, the observers must be divided into several groups and the demonstrations repeated.

The material necessary consists of—

1. Three pounds of Harbutt's plasticine in contrasting colours; white is to be avoided since it so quickly becomes soiled, and yellow can be used instead.
2. French chalk or finely powdered talc ($\frac{1}{4}$ lb.).
3. A cricket ball, or similar-sized smooth solid ball.
4. An unused hexagonal pencil.

In order to cut sections in plasticine, florist's wire can be used, as a knife is quite useless for cutting clean sections without crushing them. To save the wire being held by a second person it is useful to stretch it on a two-pronged fork of the dimensions shown in the accompanying sketch (Fig. 4). Plasticine is soluble in benzine, and if it is desired to mould it on to a surface without sticking, the surface should be well dusted with talc. In the production of these models no powers of artistic moulding are necessary !

1. THE DEVELOPMENT AND EARLY SEGMENTATION OF THE EGG OF AMPHIOXUS

The egg of Amphioxus is represented by a solid ball of plasticine two inches in diameter, with a small dot of different coloured plasticine stuck on to the upper surface to represent the polar body. The first three cleavages are then shown by two vertical and one horizontal fissures, made with the cutting-fork, and the cells so formed may be rounded at their corners to give added realism ; when placed together again, slight pressure will make them retain their correct form and positions. After this, since segmentation becomes irregular, the outline of the cells should be scribed on the surface of the morula. The manner in which the solid morula becomes a blastula is then explained.

The blastula is then formed in the following way :

The cricket ball is liberally dusted with talc, and a layer of plasticine one-quarter of an inch thick is moulded evenly over it : this covering is removed by cutting equatorially, and the two halves are placed together to make the hollow blastula. It is not necessary to fix these together, for it is obvious that in order to see inside the blastula, and to remove the cricket ball, the plasticine must be cut open. The next stage to be shown is gastrulation. One side of the sphere is invaginated into the other, and then the two rims of the so formed cup are worked together. The rim comes where the blastula was originally cut in half. Since the inside of the blastula was well coated with talc, the two layers will not stick together but remain separate, representing the primitive ectoderm and the primitive endoderm. The two-layered cup is now closed in round the thumb, the hole in which this rests representing the blastopore. Along the dorsal side a thin strip of different coloured plasticine is laid to represent the cells which differentiate to form the neural plate, and the hexagonal pencil well dusted with talc is laid along this and over the top of the blastopore. The plasticine is then worked up from the posterior end, over the pencil and along the side of it, until it meets over the top and encloses it, thus forming the neural tube. When the pencil has been completely enclosed, except for a short length at the anterior end, it is depressed, and then a quarter turn loosens it

sufficiently to enable it to be withdrawn without damaging the structure of the neural tube.

The effect of depression is to form two lateral grooves along the inside of the enteron beside the neural plate. These grooves, in reality, later become divided to form the mesodermal pouches. These show up very clearly when a transverse section and vertical longitudinal section have been cut with the wire-cutter. Beyond this point the demonstration cannot be carried.

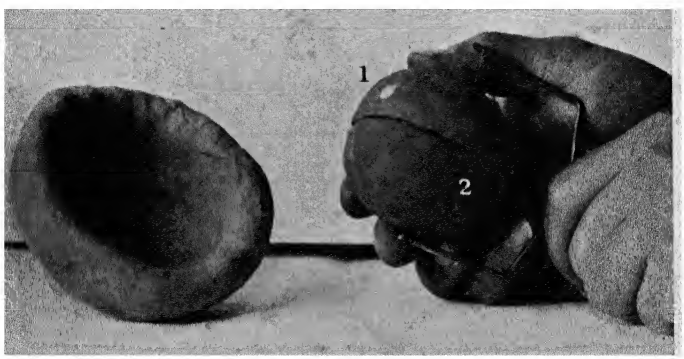
A median vertical longitudinal section is then cut, which shows the following features :

1. The primitive ectoderm, or epiblast.
2. The primitive endoderm, or hypoblast.
3. The archenteron.
4. The neurenteric canal.
5. The neural tube.
6. The neural plate.

A transverse vertical section shows the same features, except that the neurenteric canal is not present, but on the other hand the groove, which later forms the mesodermal pouches, is clearly defined.

The embryological development of the frog can also be demonstrated by this method, but it is not quite so satisfactory, since epiboly is more difficult to simulate than simple invagination. It is desirable that the blastula should be made in two colours, the upper half dark, and the lower half light, to represent the yolk-filled cells. The upper

half must be at least half an inch, and the lower half not more than a quarter of an inch thick. After moulding into shape on the cricket ball, the two halves are removed, and the rim of the lower half is turned in and the upper half forced over it. Since there is more dark material, this can be done easily, but the lower half must be well covered with talc to prevent sticking. The yellow half will

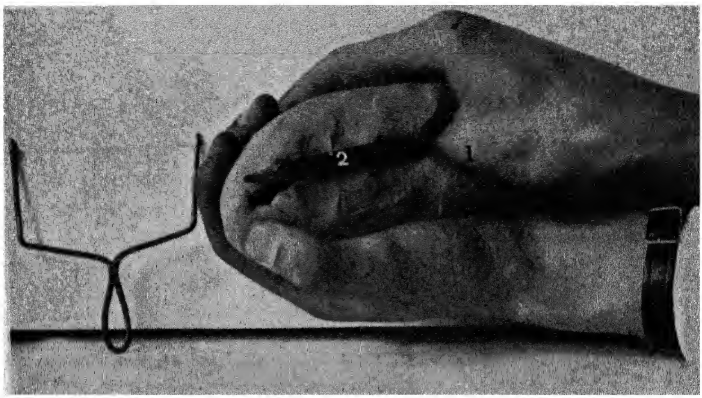


[*Photo by W. D. Brown.*

1.—Polar Body. 2.—Equatorial Division.

FIG. 1.—THE GASTRULA AND EARLY SEGMENTATION.

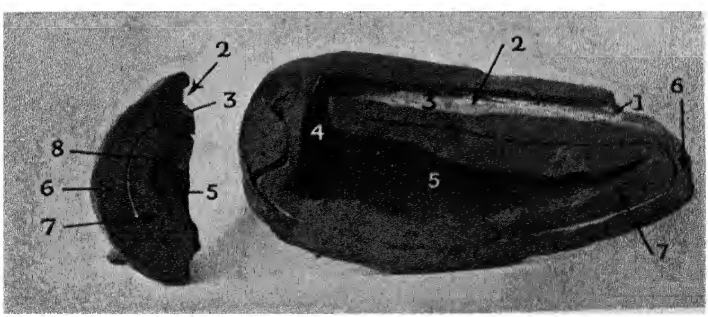
now be carried round inside, and the gastrula thus formed. This, of course, is not a perfect representation of what occurs, but it is the nearest approximation possible, and is helpful. One side of the upper half is closed more rapidly than the other (the lip of the blastopore). Closure is continued until only a narrow slit remains, which has the yellow hypoblast showing through it. A small plug of yellow



[*Photo by W. D. Brown.*

1.—Thumb in Blastopore. 2.—Pencil lying over neural plate.

FIG. 2.—CUTTING FORK AND LATE GASTRULA STAGE.



[*Photo by W. D. Brown.*

1.—Neuropore. 2.—Neural Tube. 3.—Neural Plate.
4.—Neurenteric Canal. 5.—Archenteron. 6.—Epiblast.
7.—Hypoblast. 8.—Early Stage of mesodermal pouch.

FIG. 3.—T.S. AND L.S. OF DIPLOBLASTIC EMBRYO.

plasticine is placed at each end of this, and the slit is closed. The two plugs represent the position of the neurenteric canal, and the point where the proctodæum will break through. Above the neurenteric canal a strip of plasticine should be laid to represent the neural plate, and enclosed in the same way as that of Amphioxus. (See page 6.)

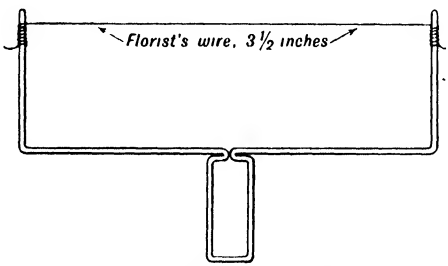


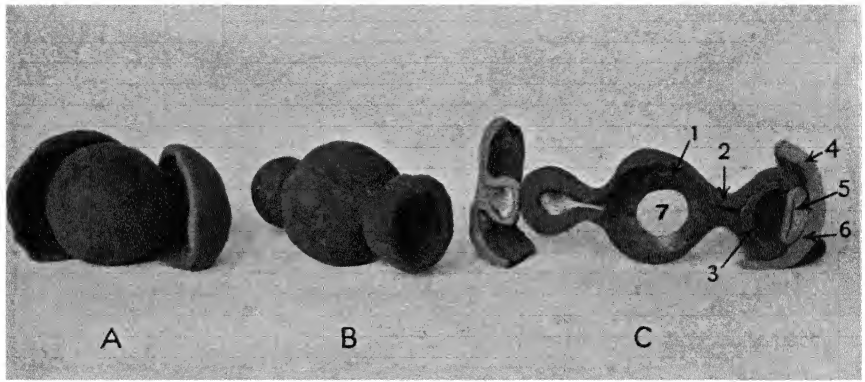
FIG. 4.—WIRE-CUTTING FORK.

After the pencil has been removed, sections can be cut to reveal the enteron, the remains of the blastocœle, the yolk-plug, the neural tube, and the endoderm in yellow plasticine, which will be found to have formed a complete lining all round the interior of the "embryo." As a practical lesson the students can model the stages for themselves, and then immediately study and draw prepared microscopic sections.

2. THE EYE OF THE CHICK

The part of the chick which is included in this model is simply the fore part of the brain and the ectodermal layers in immediate contact with it.

The brain is formed by a sphere of plasticine, half an inch thick, moulded round a cricket ball previously well dusted with talc. The ball is left inside until the final section is cut, to prevent collapse of the " brain." By outward sliding pressure the plasticine is stretched to form one optic cup, whilst similar pressure on the opposite side will form the other (Fig. 5B). The base of the cup is constricted to form the optic stalk, and at the same time the end of the cup should be forced in to make the concave retina with its two layers of cells (Fig. 5B). It is convenient to carry one side farther than the other, in order to show, when sections are cut, two stages without the necessity of making two models. Finally, the margin of the more complete retina should be turned in slightly to form the correct bulbous outline. All the above development actually occurs from the forebrain, at the same time as the lens and cornea are being developed, in reality, from the overlying ectoderm. This should be formed in different coloured plasticine. Two five-inch plaques of plasticine rather less than a quarter of an inch thick are used to represent the ectoderm in this region (Fig. 5A). These should be well powdered with talc in the centre on both sides, and a depression made which is the beginning of the buckling which forms the lens. This is deepened to a U-shaped hollow one inch deep, and then nearly pinched off (Fig. 5C). The plaque, which is to be attached to the more



[*Photo by W. D. Brown.*

FIG. 5.—MODEL SHOWING FORMATION OF CHICK'S EYE.

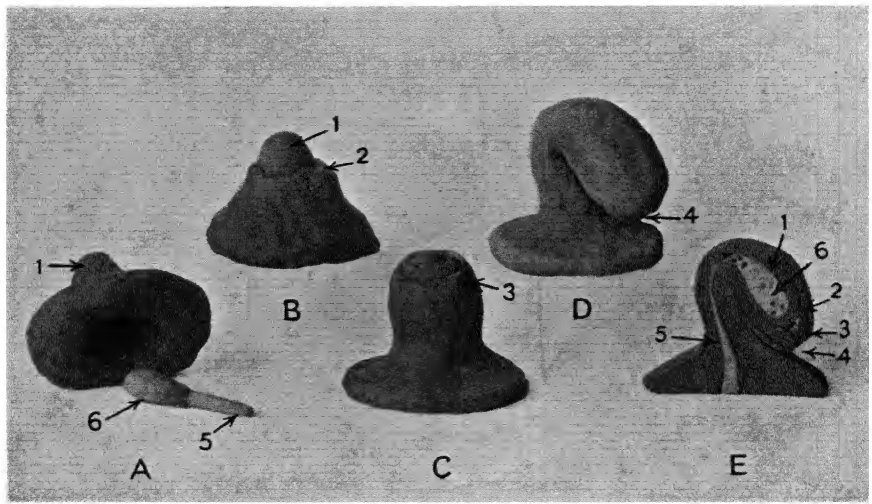
A, Forebrain and epiblast; B, Forebrain alone with optic cups; C, Section with left hand partly finished and right hand completed.

1.—Forebrain.
2.—Optic stalk.
3.—Retina.
4.—Epiblast.
5.—Lens.
6.—Cornea.
7.—Cavity leading to mid-brain.

complete side of the brain, has the lens compressed to its correct shape and the centre hole closed by plasticine from each side of the depression, thus giving three layers altogether, viz. : two layers in the lens, and one outside it, representing the cornea. The two plaques can then be joined to the optic cups on their respective sides, and, after a piece of plasticine has been sliced from the " forebrain " to show the cavity leading to the midbrain, the whole model should be sectioned. It is advisable at this point to stress the time relations, in order to make sure that no false ideas have been gained by the class, owing to the necessity of working on the ectoderm and forebrain separately. The photographs (Fig. 5A, B and C) show the degree of accuracy which can be obtained under ordinary working conditions. The models have not been touched up, and the various layers have not merged but are quite distinctly visible.

3. THE ANGIOSPERM OVULE

This is formed in the following manner : a disc of green plasticine, about three inches thick and one inch in diameter, is made to represent a small portion of the ovary wall. A protuberance is forced up on one side, the inside wall of the ovary, by pushing one finger into the outside wall, care being taken not to push the finger right through the plasticine. This leaves a hollow space, which does not occur in reality but is unavoidable.



[*Photo by W. D. Brown.*

FIG. 6.—AN ANGIOSPERM OVULE.

1.—Nucellus.
2.—Inner integument.
3.—Outer integument.
4.—Micropyle.
5.—Vascular bundle.
6.—Embryo sac.

Explanation must be made of this inaccuracy. Into the cavity, which must be well powdered, is placed the embryo sac, which in reality arises by proliferation of cells in the region of this false cavity. The embryo sac is formed from a spheroidal piece of yellow plasticine, on the base of which is stuck a disc of green with a red stalk. The stalk is the vascular strand, and the green disc separates it from the embryo sac, since the strand does not in reality pass into the latter (Fig. 6A, 5 and 6). The vascular strand must be well powdered, since at a later stage it must both slide and stretch. Immediately below the embryo sac the cavity is constricted, to prevent the latter falling out, and the model can then be placed on the table. The outside of this protuberance is the nucellus, and should stand about one and a half inches high. It must now be smoothed over carefully, and dusted with talc so that the first integument can be worked up evenly round the nucellus (Fig. 6B, 2). This should be carried on until the micropyle is almost closed, since this works more satisfactorily than starting the second integument before the first is complete, as occurs in reality. A short blunt pencil is inserted in the micropyle to prevent complete closure, and the first integument, after being smoothed and powdered, has the second integument worked over it in a similar manner. The result of this is to form an erect orthotropous ovule, and the demonstration may stop here, but, since anatropous

ovules are so common, it is better to proceed. The base of the ovule below the embryo sac is constricted rather more, and drawn upwards until it is long enough to allow the ovule to turn right over on itself with the micropyle facing the "base" (Fig. 6D). A median longitudinal section, cut with the wire-cutter, will expose the embryo sac and the vascular strand, which will be found to have been drawn right up the funicle, and to be just separated from the embryo sac by the green disc previously inserted (Fig. 6E). The antipodal cells, fusion nucleus, and egg apparatus should be scribed on the freshly displayed surface of the embryo sac. The two integuments will be found to have retained their individuality. The photographs are of actual models made by this process, but the chief value lies in the formation of each successive stage on one model, and the climax is reached when the section is cut, and a certain amount of scepticism in the minds of the class set at rest.

It might be thought that plasticine is not in any way permanent. This is true, but, provided that the models are treated with reasonable care, they can be kept in perfectly good condition, and, if stuck on a wooden base to save handling, will retain this state indefinitely. Where the cost of expensive models is prohibitive this may prove an additional advantage.

4. AN ALTERNATIVE METHOD OF FORMING PERMANENT MODELS IN PLASTER OF PARIS

As a rule it is best to use dental quality plaster of Paris, which can be bought for about sixpence a pound at most chemists. As one pound is sufficient to make a number of models, this material is quite cheap, and has been used with success in each of the following ways :

(1) For making casts of actual organisms.
(2) For making " copies " of specimens such as leaves.
(3) For making sectional models to illustrate structures.
(4) For modelling microscopic organisms.

Some details will be given of each process, and examples of work done will be quoted.

(1) For making casts of such things as the foot-print of a dog, or the webbed foot of a duck, it is only necessary to press the required object into soft clay, plasticine, or anything firm enough to take and keep the imprint. The powdered plaster is placed in an old cup or mug, and sufficient water added to make, after stirring, a mixture just thin enough to be poured out. This must be done rapidly, for plaster sets very quickly unless a really thin mixture is used. The mixture is poured into the clay mould, and left till it has set. The time taken to set depends upon the thinness of the mixture of plaster and water, but is never more

than a few minutes. The plaster cast is then quite complete.

In the laboratory it is probably best to make the imprint in plasticine, for the resulting surface is quite clean, as the plaster does not stick to the plasticine. A complete model of a real object may easily be made. First of all the object can be coated with plaster or warm wax, and the mould made in two pieces. If plaster is used, this mould must be coated with vaseline, and a positive made from it. This is the method used by dentists when making artificial teeth, but can be used for modelling the body of a fish, or the shape of a twig.

(2) The method used here is very similar to the above, and the results are often very beautiful. When it is desired to make a copy of a leaf, the leaf must be rolled on to a smooth surface of plasticine, or the modern alloplast which serves equally well. For rolling, a small rubber roller or squeegee is best, though it has been found that a glass jam-jar or bottle serves quite well ! The leaf is removed from the plasticine very carefully. The plasticine is now placed in a small flat tin or box so that the plaster, when poured in, will be kept within bounds. The plaster, of just sufficient thinness to pour, is mixed as above and poured over the plasticine, and then left until it has set. The result is often so detailed as to stand inspection with a high-power lens. One additional advantage of this is that the plaster model can be painted,

and a most lifelike result obtained. Water paint "runs" very little on plaster of Paris, so that the appearance is not spoilt by painting. It is quite unnecessary to have a thick cast; a model a quarter of an inch thick is strong enough to withstand a considerable amount of handling.

(3) The value of this use of plaster is that it gives to a student a three-dimensional conception of a solid body. As already mentioned many students experience difficulty in interpreting a blackboard drawing in three dimensions, and here models are of great use. In practice, it is well to place sufficient dry plaster for the model, or models, on an ordinary enamel plate, and pour over this half its volume of water. The mixture is stirred, and the resulting paste quickly moulded with the hands to approximately the shape required. In two minutes the plaster will have set, and the resulting body can be shaped to any desired form by the use of a penknife. The writer has, for instance, made a shape to represent a horizontal median section of a Chlamydomonas cell. The two cilia were made of fine copper wire in the form of a loop buried in the plaster, the free ends, which are quite pliable, representing the cilia. In this model a little of the plaster should be scraped away from the inside, to leave the nucleus standing as a slightly raised lump. A thin furrow should be scribed, to separate the protoplast from the cellulose covering, before the whole is suitably

coloured. In a similar way a model of Euglena with green chloroplasts can be easily made.

(4) Any microscopic body can be easily modelled : e.g. the sporangium of the bracken fern with its raised annulus, or the stigma and style of a flower, with lines to represent the passage of pollen tubes.

Amœba, which is included in most elementary syllabuses, can be made in quantities. Four or more models of amœba of different shapes should be made in plasticine, and pressed gently into soft plaster of Paris. When the plaster has set, the plasticine is removed, and the moulds thus formed smeared thinly with vaseline. The mould can then be filled with plaster of Paris as described above, and the process repeated until a sufficient number of models have been produced. These are suitable for junior boys, who can use indian ink to add nuclei, contractile vacuoles and the granular appearance.

Paramœcium may either be carved from a large block of plaster, or produced from moulds in the same way as amœba. The cilia can be made from short lengths of wire, and the nucleus, contractile vacuoles, and food particles drawn on the surface.

There are two good points about plaster work : it is not dirty, most results being quite clean, and boys like using it. A useful idea, developed by students themselves, deserves attention. Pictures of butterflies, caterpillars and chrysalids were cut out

of cardboard and the shapes pressed into soft plaster which was left to set. The resultant depressions were coloured. This proved very suitable for showing the types of metamorphosis of butterflies, and the relative colours, shapes and sizes of the four stages. Some shapes have even been cut from pictures on cigarette cards !

CHAPTER III

Constructional Models

WHILST this method of instruction is open to criticism on the grounds of leaving little room for the student to think for himself; it nevertheless has the advantage that it prevents misconception arising. Moreover, it gives a certain amount of matter in an already digested form, and clears the way for complete understanding of structure later on. If some of the work is carried out by the students themselves they are likely to learn more still.

1. THE RABBIT'S NECK

This always seems to cause unnecessary trouble during dissection, although it is quite a clean piece of work. Part of the trouble is probably due to the lack of information available in text-books, and to the difficulty of making a good drawing, which must have in it, in one plane, four or five approximately parallel lines to show the blood-vessels and nerves, which in the animal lie in different planes. This is therefore made as a "constructional" model, that is to say each part can be removed, and the whole thing put together again by placing

the correct blood-vessels and nerves in their right position as described below. The size of the model depends upon the size of the class, but, for general purposes of handling, two feet long by eighteen inches wide is of ample size, but one of smaller size would be equally satisfactory and would not take so long to make. The baseboard should be of five-ply wood, obtainable ready cut to any required size at Hobbies. On this is laid a V-shaped piece of wood about one and a half inch thick, which can be made of two layers three-quarters of an inch thick, as this is more easy to obtain. The arms of the V are rounded off at the edges until the shape approximates to that shown in Figure 7, both in surface view and in section. This wood represents the muscles at the side of the neck. This portion could be made more quickly in plaster of Paris, which is quite suitable, since it has not to stand any strain. When this part has been shaped sufficiently, according to the desire and skill of the constructor, it should be painted pale cream or pink inside, and the outer edge painted brown to indicate fur. In the central cavity, the trachea, made from a length of flexible gas-pipe, is fixed with wire staples, and the heart, shaped from wood or plaster, is placed above a cardboard diaphragm. It is better to use cardboard than tin which is liable to cut the hand of anyone working on the model. From the heart a wire aortic arch curves to the left with four project-

ing pegs (Fig. 7) which are for attachment of the arteries. Behind the heart two further pegs serve for the attachment of the jugular veins. At the opposite end of the groove corresponding pegs are

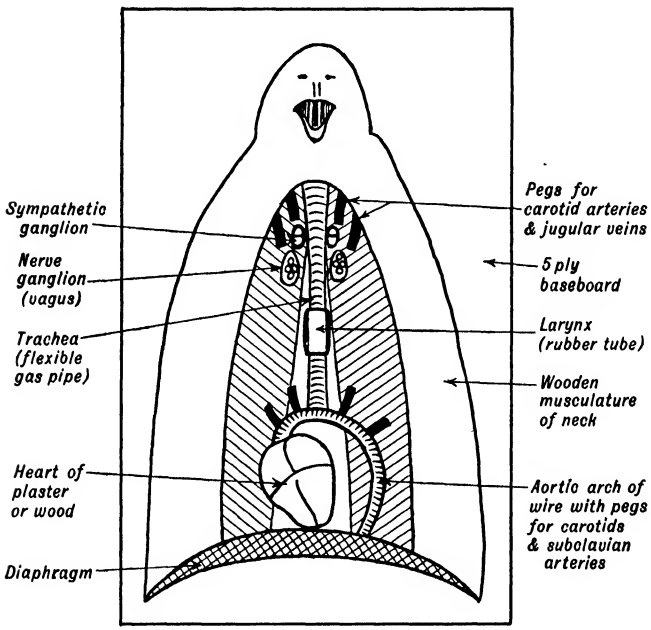


FIG. 7.—THE RABBIT'S NECK.

placed, and between the pegs are fitted lengths of black and red surgical rubber tubing, which represent the veins and arteries respectively, and may be labelled or not as desired.

The nerves are made from $\frac{1}{8}$-inch wire painted white, and preferably labelled. Each of these has a short portion at each end bent at right angles, to fit into holes drilled either into the baseboard or the muscular wall, according to their correct position. To ensure that each nerve shall go into its correct place, it is a good plan to make them of different lengths : a quarter of an inch difference is quite enough to secure this result. The nerve

Section showing trachea, nerves & blood vessels.

FIG. 8.—A SECTION OF THE RABBIT'S NECK.

ganglia are made from plastic wood shaped correctly and nailed down. This wood will stand drilling with $\frac{1}{8}$-inch holes for the insertion of nerves and does not split. The best method of using this model is to describe the neck structure briefly, and then take the whole thing to pieces and make the students put each blood-vessel and vein into its correct place. Trial and error will soon produce the correct placing. It is a great advantage if the students themselves assist in making the model.

2. THE MAIN SKULL TYPES

The demonstration of the main skull types, Anapsid, Synapsid, Parapsid and Diapsid, is usually given with the aid of wall-charts or sketches made

on the blackboard, followed by a practical lesson with as many actual examples as possible of the skulls described. There appear, however, to be two disadvantages in the early part of the demonstration, namely, that wall-charts do not leave a very vivid impression on the mind, and that drawing on the board is slow, laborious, and seldom more impressive than wall-charts. The method below provides a variation of approach, though of course it is essential that it be followed by study of real skulls, at least turtle, lizard, bird and dog.

A diagrammatic skull, in three-quarter rear view, is drawn on a piece of three or preferably five-ply wood. The size of the outline is governed solely by the number of students in the class, but, for twelve students to see it easily, the skull should be about a foot long. The squamosal, post-orbital bones, and the nasal and orbital apertures, are all cut out completely with a fretsaw. The two posterior arcades and the foramen magnum, which are visible owing to the semi-perspective view of the skull, are also cut out (see Fig. 9). The squamosal and post-orbital bones may be coloured bright red and yellow respectively, whilst the other bone of importance, the post-frontal, can be coloured green. The remainder of the skull is painted white, and the sutures between the bones, and their respective names, painted in black. The skull with the squamosal and post-orbital bones inserted now represents the anapsid type.

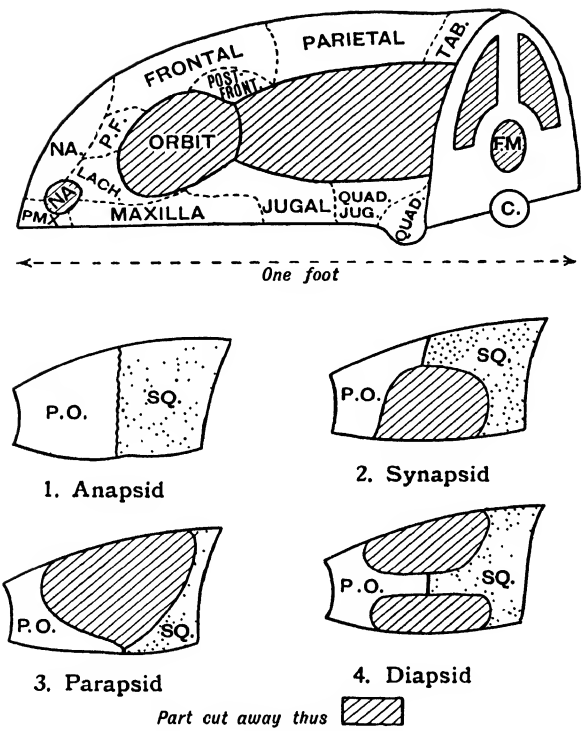


FIG. 9.—A PLYWOOD SKULL.

P.O.	= Post orbital.	Quad. jug.	= Quadrato jugal.
Sq.	= Squamosal.	Quad.	= Quadrate.
Tab.	= Tabular.	Lach.	= Lachrimal.
Post. Front.	= Post Frontal.	P.F.	= Pre-frontal.
PMX	= Pre-Maxilla.	Na	= Nasal bone and aperture.
C	= Condyle.	F.M.	= Foramen Magnum.

Three further sets of post-orbitals and squamosals are made to fit exactly the space made by the removal of the original post-orbital and squamosal. Each pair is made a different shape to represent :

1. A synapsid skull, with the post-orbital bordering the upper edge of the temporal vacuity.
2. A parapsid type, with the post-orbital bordering the lower edge of the temporal vacuity.
3. A diapsid type with T-shaped squamosal and post-orbital.

By removal of the original post-orbital, and the substitution of the parapsid squamosal, an approximation to the bird's skull is obtained. The back of the " skull " can be painted white with the bones picked out but unnamed, and, as an exercise, the class can be asked to recognize the various bones and types of skull with no assistance save the shape and relative position of the bones. Another skull may be cut up completely like a jig-saw puzzle, and used for revision or preparation work, and, since the above frame cannot be made to represent a mammalian skull, it is useful to make this completely dissected " puzzle " in the form of a mammal's skull with the articulation of the lower jaw on the squamosal. It is neither a long nor an arduous task to make these demonstration skulls, and, once the drawing has been made, they can easily be cut out, if necessary, by a laboratory assistant with no particular knowledge of zoology or of skulls.

3. THE CELL OF SPIROGYRA

A large-sized reproduction of a cell of spirogyra can be made from a large diameter glass tube, such as a chimney used for the protection of a gas mantle. The chloroplast must be drawn out on a piece of springy cardboard, or paper, which is rolled into a tube the same size as the glass tube. The cardboard may then be laid flat and the chloroplast cut out, painted green, coated with seccotine and coiled up again. This time it is coiled tightly and pushed inside the cell; when inside it will uncoil and stick to the inner wall. The glass represents the cellulose wall of spirogyra, and the protoplasm is represented by a layer of collodion, preferably tinged yellow to distinguish it from the glass wall. The protoplasmic strands which support the nucleus are formed from thin glass rods fused together in the centre. Since they are light, a touch of seccotine will hold them in place. Where they meet in the centre a nucleus of plasticine is added. Pyrenoids formed from beads of glass are stuck on the chloroplast. The end walls of the cell should be made of celluloid or mica, and should be stuck on last of all.

As damp affects seccotine, models in which it is used should be stored in a dry cupboard.

4. VESSELS, TRACHEIDS AND PHLOEM

Except that the cells made of glass in this manner are rather fragile, the method outlined above for

making the cell of spirogyra can be used very successfully to reproduce individual vessels, tracheids, and sieve tubes on an enlarged scale. The tracheids require a little skill in drawing glass tubes, but this can soon be acquired.

A. Vessels and Tracheids. The vessel is made from a twelve-inch length of one-inch diameter glass tube, which is left open at each end. Annular thickening is made from coiled paper. Almost any colour can be used except green, which is reminiscent of the chloroplast in spirogyra, and the coil can be coated with seccotine and allowed, as in spirogyra, to uncoil inside the glass tube. Spiral thickening can be inserted in the same way. Finally, the whole tube is coated on the outside with gum dammar, which makes it possible to draw in indian ink on the vessel any simple or bordered pits which may be required. Tracheids should be drawn off in nine-inch, or shorter, lengths over a bunsen burner, and it is quite easy to draw off the tapered end of the cell without any kinks. The tube is then covered with gum dammar, and the required pits drawn in indian ink.

B. Phloem. Sieve tubes are made from six-inch lengths of one-inch diameter tube, and the mucilaginous strands, commonly visible in sieve tubes between the sieve plates, are made from lengths of round elastic thread. These threads should be one inch shorter than the sieve tube, and are stuck through holes in a celluloid sieve plate with a drop

of amyl acetate. The tension of the elastic will keep the sieve plates in position, but it is advisable to stick them to the glass with a little seccotine.

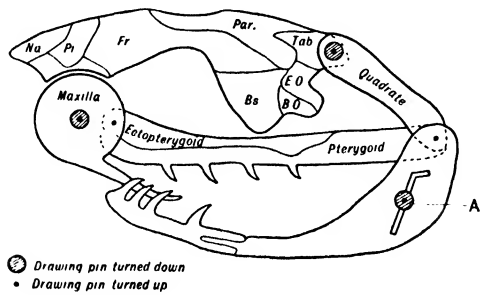
The elastic strands running straight through the cell represent the condition in a young living sieve tube. If the characteristic hour-glass appearance is desired, the strands must be passed through two cone-shaped rings of glass, cut from a tapering tube, and these should be stuck near the sieve plates. These rings are almost invisible inside the sieve tube.

5. THE SKULL OF THE SNAKE

It is not easy to represent the action of the movable quadrate in the skull of the snake by the aid of diagrams alone, and, although actual skulls of snakes may be available, they are so prepared that the quadrate is immovably attached to the skull, and to the lower jaw. Working models can be made in cardboard or three-ply wood. Although cardboard is less durable, it is better for making the model. The model is not constructed accurately, but it illustrates the principle of the mechanism whereby the gape of the jaws is made unusually large, and at the same time the poison fang is made to open outward when the mouth opens.

The accompanying diagram (Fig. 10) is made to scale and can be enlarged to any suitable size according to the number of pupils who require to see it at one time. The chief difficulty in getting the model to work is finding the position of the

pin A. A suitable position is suggested in the diagram (Fig. 10). By varying the position of the pin the varying size of gape may be obtained. The pin, of course, is an artificiality, and no such



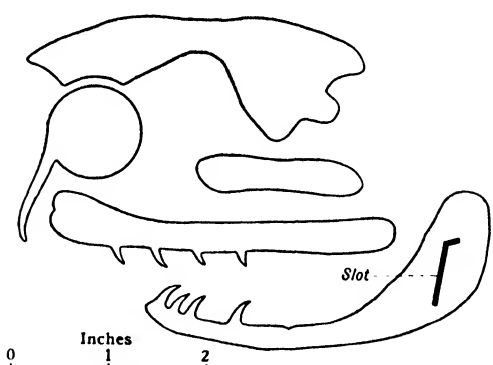


FIG. 10.—THE SNAKE'S SKULL.

fixture exists in the animal. It is necessary for the working model, however, but can be covered with a piece of paper. It has been found impracticable to make the model more vivid by inserting muscle

attachments with elastic bands. All that is required to open the mouth is a push downwards at the point of articulation of the quadrate with the lower jaw.

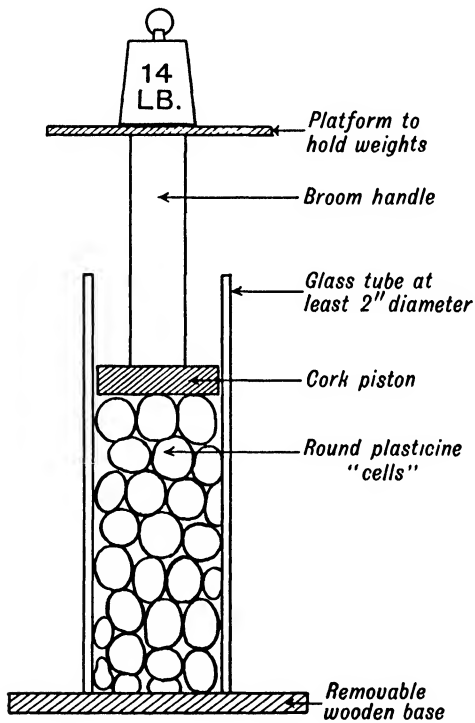


FIG. 11.—A CELL-PRESSURE EXPERIMENT.

6. CELL PRESSURE

A strong glass tube two inches in diameter is filled with soft, well-rounded plasticine balls covered with powdered talc. The tube is placed vertically

upon a solid wooden board, and a piston, composed of a cork and a length of broom-stick, placed on the top (Fig. 11). Weights amounting to about 14 lb. are placed upon the platform, and left for several hours. The plasticine balls take up angular and square shapes similar to the shapes associated with xylem in transverse section, or tightly packed parenchymatous cells. It is easy to remove the "cells" by pushing them straight through the tube, and, as they usually stick lightly together, they may be sectioned with the cutting wire mentioned in Chapter II, Section 1.

7. VASCULAR TRANSITION FROM ROOT TO STEM

The easiest form of root to make is the diarch type, and plasticine is the most convenient material for the model because it can be twisted into shape. Two rolls of plasticine three-quarters of an inch in diameter and nine inches long are flattened into triangular section, and pegged together with match-stalks, along half their length. These represent xylem, and, if desired, a strip of different coloured plasticine can be stuck along the outer edge of each strip to represent protoxylem.

On opposite sides of this diamond-sectioned strip, two oval rolls of contrasting coloured plasticine are pegged for half their length, their upper end being left free. These represent the phloem. The upper half of both xylem and phloem strands are then split in half with the wire-cutter described in

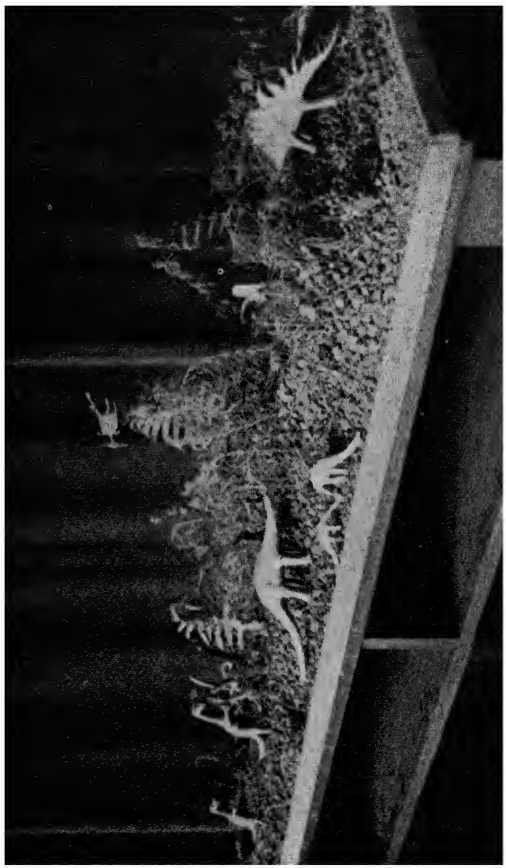
Chapter II, Section 1. The four xylem strands are twisted through 180° to bring the protoxylem near to the centre, and the four phloem strands bent to lie outside the xylem to which they are pegged. It is a good thing to run lengths of copper wire inside the xylem to give it greater rigidity.

The endodermis is conveniently formed of a $4\frac{1}{2}$-inch length cut from an old gas jar about two inches in diameter, and the epidermis, which should be about three and a half inches in diameter, can be made of celluloid, a piece of which, nine inches by twelve, will just roll up to form such a tube, the joint being stuck with amyl acetate. If the endodermis is painted over with gum dammar, cells can be drawn on it with indian ink.

Both the endodermis and the epidermis may be stuck to a piece of glass about six inches square with Murrayite cement, which is very strong. It is convenient to leave the vascular portion loose so that it can be removed for inspection, though it is easily visible through the celluloid epidermis and glass endodermis.

8. LANDSCAPE MODELLING

There is no end to the scope of this type of modelling, but its application can be made most interesting by the construction of extinct animals, and the setting of these in suitable surroundings.



[*Photo by W. D. Brown.*

FIG. 12.—GENERAL VIEW OF CRETACEOUS SCENE.

Of course full-sized and reduced scale models are to be found in museums and public gardens, but the possibility of taking a class to these places is remote, and the most likely advantage to be taken of these models is for the teacher to go alone and use them for inspiration. The accompanying photographs give some idea of the possibilities of modelling, and the method of construction is briefly as follows :

Models may be made of any types of prehistoric creatures, but the Jurassic and Cretaceous periods offer the great advantage of a number of reptiles, all interesting to children. Most of these reptiles have a simple outline and can be placed in a setting of live ferns and horse-tails (*equisitum arvense*).

Construction should be carried out as far as possible by members of the class, and this work is particularly suited to middle-school forms. A convenient scale to work to is two feet to the inch, and a laboratory table about $5 \times 2\frac{1}{2}$ feet forms an admirable base-board, though obviously any large-sized tray or table can be utilized. A couple of buckets of fine gravel, and a little sand spread in an undulating manner, form the natural ground, and small slats of wood at the edge of the table prevent any of the sand or gravel falling off. In one part the gravel may be heaped up round and into a large developing dish which forms a pool, the water in which will pass into the gravel by

capillarity and keep the gravel and sand moist. The foliage consists of live horse-tails (*equisitum*), planted in the gravel, which owing to the moisture keep fresh for a considerable time. The fern fronds must be planted in specimen tubes full of water in

[*Photo by W. D. Brown.*

FIG. 13.—CLOSE UP OF CARNIVOROUS AND HERBIVOROUS IGUANADONS.

order to keep them upright and give them an adequate water supply. The specimen tubes are easily hidden in the gravel, and both the ferns and the horse-tails should be about twelve inches high. Dead fern stems can be represented most realistically

by bracken rhizome, and cacti and plants of the araucaria family can be made in green and brown plasticine. These are useful in arousing jealousy and competition between the artists constructing them and those making the reptiles, especially as the latter consider themselves superior. Many of the students will show unexpected talent and skill. The animals are all made from brown and grey plasticine, and reinforced in the legs and body with match-stalks and wire where necessary. Models on the scale of two feet to one inch vary in size from six to twelve inches in height, and the longest is about eighteen inches long, and they are not difficult to copy from text-books sketches and plates. Models on a scale of three feet to one inch require much less plasticine. The following models are merely suggestions and figure in the accompanying plates.

1. A small carnivorous iguanadon, about seven inches high.
2. A large herbivorous iguanadon, ten inches high.
3. A medium-sized diplodocus, fifteen inches long.
4. A large pterosaurus, with a wing span of six inches, supported on a vertical wire hidden in a horse-tail.
5. A stegosaurus, seven inches long. This is difficult to make.

6. A dimetrodon, not found in cretaceous rocks, but a great favourite on account of its curious appearance.

Useful post-card illustrations of the above animals can be obtained from the Science Museum, South Kensington.

CHAPTER IV

Laboratory Apparatus

I. AN ARTIFICIAL HOTBED FOR THE RAPID GERMINATION OF SEEDLINGS

This simple apparatus is inexpensive to construct and cheap to run. It is a handy adaptation of the ordinary greenhouse method of forcing plants.

The type of box most suitable is a tinned fruit-case, or orange box, with a false bottom fixed at half the depth available. Upon this is placed a two-inch layer of ordinary soil, which is covered with a similar layer of fibrous potting soil from a seedsman; this enables the young roots to be removed undamaged. In the lower part of the box is fixed a Woolworth sixpenny fifteen-watt electric-light bulb, if possible in a vertical position. This, worked from the mains, maintains, even in the coldest weather, a soil temperature of 16°–18° C. (65° F.). Loss of heat and water are reduced to a minimum by the use of a cloche of common horticultural glass made to fit the box. This is also easy to construct. The glass is cut to size and joined at the corners by strips of thick brown paper one inch wide, glued with ordinary glue and strengthened with ½-inch square strips of wood

internally. The paper will not show any tendency to come unstuck even after several years' use, and in any case repairs are easily effected. The dimensions are shown in Figure 14, and the ventilation

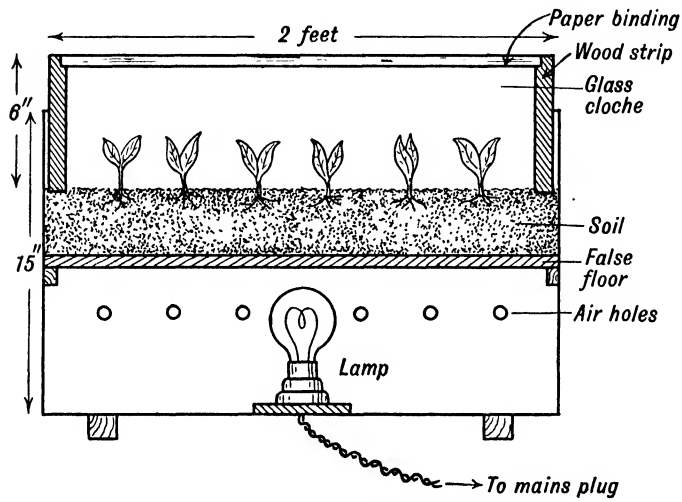


FIG. 14.—AN ARTIFICIAL HOTBED.

holes to the light chamber are useful to allow air circulation and the maintenance of an even temperature. Part of the bottom of the box should be removed to get at the electric bulb if necessary. The box should be placed in a window where the light is good. This apparatus can be modified for breeding Drosophila.

2. A SIMPLE EMBEDDING OVEN

This apparatus can be left for an unlimited time at a constant temperature of 55°–60° C. when once

it has been adjusted. It consists of a glass vessel containing ordinary motor-car engine lubricating oil. In this a sixty-watt electric-light bulb is immersed to a depth of about two-thirds of its

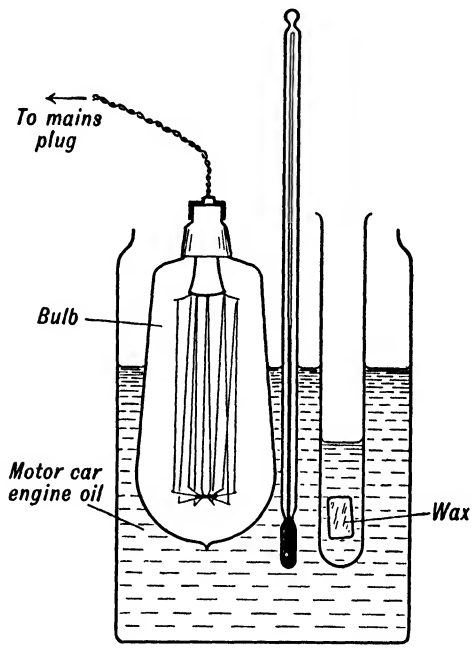


FIG. 15.—AN EMBEDDING OVEN.

length so that the required temperature may be maintained. This temperature is reached in about half an hour, and a sixty-watt bulb can maintain it indefinitely. The temperature varies according to the depth to which the bulb is immersed.

Wax and the material impregnated with xylol

are put into a clean test-tube and dipped in the oil, in which the test-tube is too light to sink. Here they remain until they are completely impregnated, when they can either be chilled in the test-tube and removed by local heat, or set up in a wax block by the usual paper-boat method ; both methods are satisfactory.

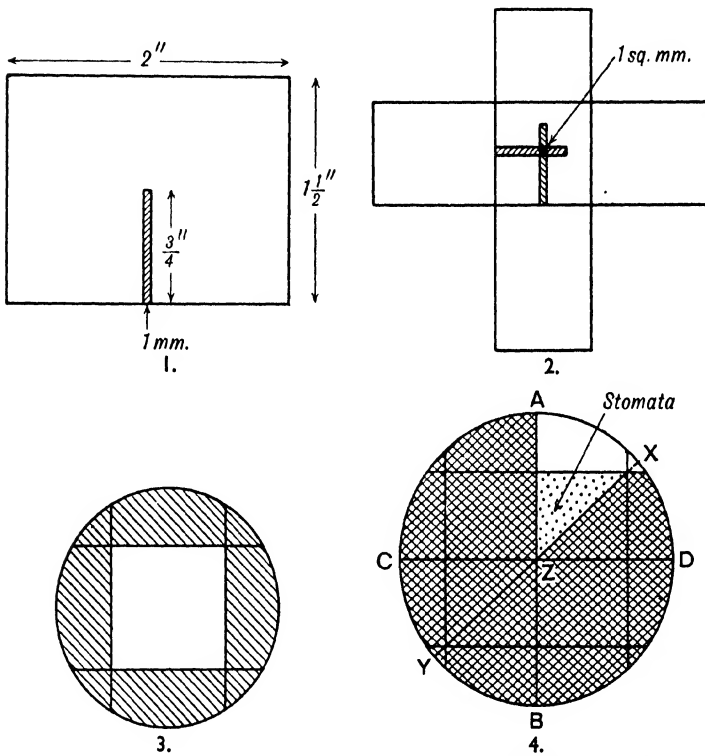
3. A SIMPLE METHOD OF COUNTING STOMATA ON LEAF EPIDERMIS

The method of counting stomata described below has three advantages over that requiring the use of a graduated disc and scribed slide. The result is a direct reading with only one simple calculation, and at the same time the area under observation is quite definite and is one square millimetre. No expensive graduated disc is needed. This costs about 10*s*., and only one member of a class can use it at a time. The method is not difficult to explain, and is suitable for use in upper forms at school, or in a university elementary course.

The process is as follows :

Along the straight edge of a sheet of plain paper, about the thickness of ordinary foolscap, two marks, one millimetre apart, are made with a sharp pencil. From these, two lines about three-quarters of an inch long are drawn at right angles to the edge, and the slit thus formed is cut out with a sharp pair of fine scissors. A piece of the paper about two inches long and one and a half wide is cut off

so as to include this slit. The result will be a rectangle of paper with a slit in it one millimetre wide (Fig. 16 (1)). A second precisely similar



1 square millimetre as seen under low-power microscope. ⅓ objective and No. 4 eyepiece.

¼th of square millimetre with visible stomata easily countable.

FIG. 16.—COUNTING STOMATA ON A LEAF.

piece of paper is cut, and if these two pieces of paper are laid over each other with the slits at right angles, the aperture formed is exactly one

square millimetre (Fig. 2). A piece of leaf epidermis is next laid on a slide, and mounted in glycerine, and the two papers placed over it so that one square millimetre of epidermis is visible. Another slide is placed on top, and to prevent any slipping the whole should be clipped to the microscope stage. This should now be observed under the low power ($\frac{2}{3}$, or if available $\frac{1}{3}$ objective), and a number 4 or 5 eyepiece used. It will then be found that the square millimetre does not quite fill the field of view (Fig. 16 (3)). Now the number of stomata on a leaf of laurel is about 250 per square millimetre, and it is very difficult to count such a large number under such a low magnification. To get over this difficulty a part of the field must be obscured, and this is done as follows. The eyepiece of the microscope is removed, and a circle drawn either round it, or, with the compass, on a sheet of paper. A compass is a great help as this circle must be about two millimetres less in diameter than the edge of the eyepiece into which it must fit. This circle is first divided by pencil lines into halves, and then into quadrants, as accurately as possible, and finally one of the quadrants is bisected. The disc can then be cut out, and one of the half-quadrants carefully cut away. The circle is then placed in the eyepiece and rotated until one of the bisecting lines is horizontal. The slide below must next be moved so that the centre of the square millimetre is in the centre of the circle. This is

quite easy, and on observation it will be found to look like Figure 16 (4), AB and CD both dividing the square into equal rectangles and XY running from corner to corner. The part of the leaf visible will be shown in the $\frac{1}{8}$-part of the circle (AZX). It follows that this is exactly one-eighth of a square millimetre, if the drawing has been done reasonably accurately, and consequently the number of stomata will be about thirty. To calculate the number of stomata per square millimetre it is only necessary to multiply this number by eight. The lines on the disc in the eyepiece can be seen easily, and assist in centring the slide. If desired, the total area of the leaf can be calculated by drawing the outline on graph paper ruled in square centimetres and millimetres, and then counting these up accurately, or estimating them by approximation. From this the total number of stomata per leaf can be deduced.

4. THE MODIFIED POTOMETER

The principle of the apparatus described below is based upon the conventional form of potometer, but has two modifications.

1. The provision of an automatic bubble feed, which can be used to give comparative time readings.
2. A graduated supply tube, which shows the quantity of water absorbed during any predetermined period.

1. *The Automatic Bubble Feed.*

This consists of two capillary tubes, one of which forms a jet for the introduction of air bubbles into the water current (Fig. 17A). Air is drawn into the water owing to the reduction of pressure at this jet as compared with the intake (Fig. 17B). The intake consists of the second of the above mentioned capillaries, which is much finer than the

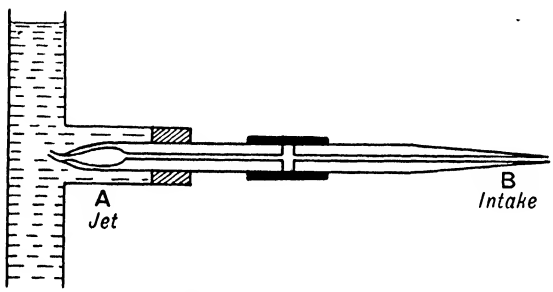


FIG. 17.—AIR INTAKE FOR THE MODIFIED POTOMETER.

jet, and controls the frequency of the bubbles. The method of drawing these capillaries is important. The jet is best formed by drawing out a small bulb blown at the end of ordinary capillary tubing, one millimetre in diameter. This method is adopted to make the walls sufficiently thin to form a small bubble of air. To construct the intake, a similar piece of capillary is sealed off, and a thread drawn out with a glass rod. Small pieces are then broken off until the desired aperture is obtained. The two capillaries are joined by a short length of tight-fitting rubber tube.

2. *The Graduated Supply Tube.*

A tap-burette has two side tubes (Fig. 18c and d) fused into its open end. One of these, D, has a bore of about one-tenth of an inch, and is fitted with a stopper made of rubber tubing plugged

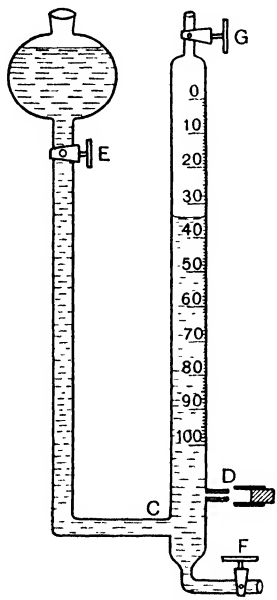


FIG. 18.—WATER-SUPPLY FOR THE MODIFIED POTOMETER.

with a piece of glass rod. The other, C, is connected to a suitable reservoir with a tap, E. From the open end of the burette a delivery tube leads to the remainder of the apparatus and is fitted with a clip or tap, F. In use the two taps G and E are closed, the tube D is opened, and finally the clip F

is removed to let water flow to the plant. Air enters by the tube D to replace the water absorbed, and the supply is thus maintained at constant pressure. To refill the burette F and D are closed and E and G opened.

Assembly and Use of the Apparatus.

The apparatus can be assembled in two forms. In the first place it may be used for display purposes, to demonstrate water absorption, or to give comparative time readings under varying conditions in the usual way. Unless water absorption ceases, it requires no attention whatsoever. The second form will work continuously for three or four days, and show, in addition to the comparative readings, the actual quantity of water absorbed during any desired period.

Simple Form of the Apparatus.

Figure 19 shows the method of assembly. The bubble feed is inserted into a T-piece about six inches above the level of the water in the trough, producing a reduction of pressure which causes air bubbles to be drawn in through the jet. By altering the head H the frequency of the bubbles may be varied. The level of the trough is kept constant by an inverted flask of water. The bubbles pass along the observation capillary tube and are collected in the air-trap. The base of the shoot

should be approximately level with the water in the trough. Since the water supply becomes air-

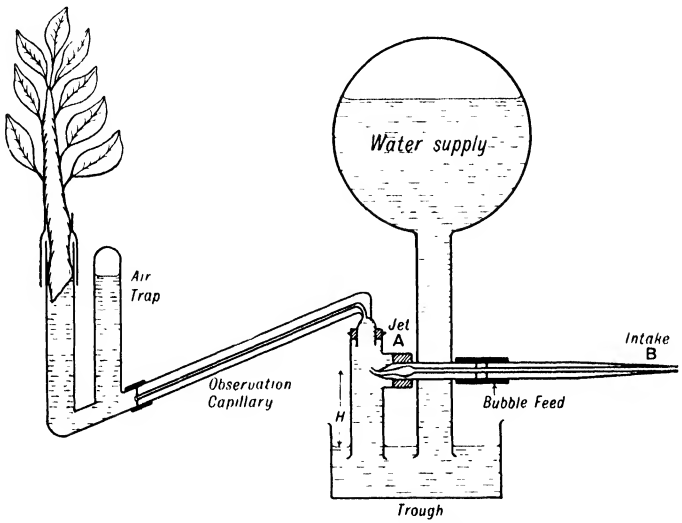


FIG. 19.—A SIMPLE POTOMETER.

locked when absorption ceases, the apparatus cannot be left over-night, unless the air supply is cut off by plugging the intake.

Complete Form of the Apparatus.

This is shown in Figure 20. The air intake is connected to the air-trap, thus making an enclosed air circuit, with the control capillary at B. The supply of bubbles depends on the head H of water in the vertical limb of the capillary tube K. If the rate of absorption decreases, the bubbles tend

to accumulate in the tube K, reducing the head H. Ultimately the supply of air ceases, until absorption starts again and removes the bubbles already present. When this takes place there is a tendency for water to be sucked back into the bubble feed, and the intake capillary is therefore placed in an

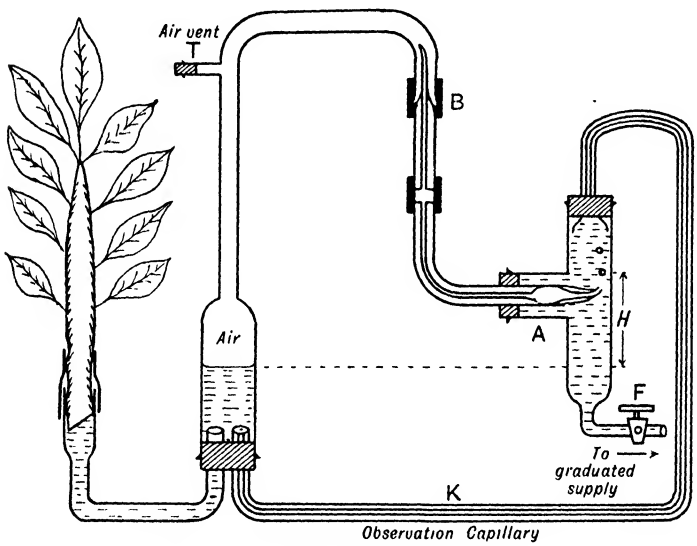


FIG. 20.—A COMPLICATED POTOMETER.

elevated position. After running for some time the supply of bubbles is automatically adjusted to the rate of transpiration, provided that a suitable size of intake capillary has been selected. To facilitate adjustment of the water level in the air-trap, a T-piece is fitted as shown (T). This apparatus is obviously more delicate than the simpler form, and

has the disadvantage that condensation is liable to take place in the control capillary (B) when the apparatus is not actually in use. When this occurs a new capillary must be made and fitted. Fortunately this defect does not appear to develop when absorption ceases at night.

The usual precautions should be observed when cutting the stem, the selected shoot is cut from the plant and immediately plunged into water. This is transferred to a large trough, and a piece cut off with a sharp razor under water, to expose a fresh surface ; after a few minutes it is transferred quickly to the apparatus.

APPENDIX

Adhesives.—1. Amyl acetate.—This is suitable for sticking celluloid. It is obtainable from most chemists. The surface of the celluloid which is to be stuck should be roughened in order to make a strong joint. Amyl acetate sets in a few hours.

2. Durofix.—This is a colourless adhesive suitable for joining wood, glass or cardboard. It is waterproof and sets in two or three hours. It can be bought from stationers and ironmongers.

3. Murrayite Cement.—This is particularly suitable for sticking glass ; it is very strong and waterproof. It is sold by leading chemists and biological dealers.

4. Seccotine.—This is a useful general adhesive for glass, wood or cardboard, and can be obtained almost anywhere. It is important to remember that it is *not* waterproof, and models in which it is used must be kept in a dry place.

Alloplast.—An alternative modelling material to plasticine which is sold by many dealers in school equipment.

Celluloid.—Usually obtainable from large chemists. If it has to be folded or bent it may be softened in hot water. The best adhesive for celluloid is amyl acetate.

Gum Dammar.—Should be bought in quantities of one or two ounces from the chemist and can be dissolved in benzole. The solution can be painted on to glass slides to enable diagrams or tables to be written on the glass in indian ink, or other coloured ink.

Plaster of Paris.—This may be bought from most

chemists in quantities of half a pound or more. It is important to remember that the rate of setting and the *final hardness* depend upon the quantity of water used when mixing the plaster.

Plasticine.—This can be bought from most stationers and toy shops ; it is advisable to buy it in $\frac{1}{2}$-pound sticks. It may be softened with vaseline, and cleaned from anything to which it has stuck with benzole.

Plastic Wood.—This is sold in tubes by ironmongers. It sets hard in about 24 hours. Its chief use is for moulding small objects and for filling in spaces (instead of putty). When hard, it has no grain, and so can be either drilled, or chiselled, or planed in any direction without splitting.

Plywood.—It is best to use five-ply wood, as this does not warp so easily as three-ply wood. Plywood can be obtained from Hobbies, Ltd., and should always be kept in a dry place to prevent the layers from flaking apart.

Slides.—Frequently it is useful to make slides for projection with a form-room lantern. Text-book diagrams can be copied on to ordinary glass if the coloured ink is thickened with a 10 per cent. solution of dextrin or office gum. A dye dissolved in dextrin will do equally well, or the slide may be painted with gum dammar when indian ink can be used, as this cannot be mixed with dextrin.

Stripwood.—This can be obtained from Hobbies, Ltd., in two-foot lengths, and almost any section can be supplied. The most useful sections are : $\frac{3}{8}'' \times \frac{3}{8}''$; $\frac{1}{2}'' \times \frac{1}{2}''$; $\frac{1}{4}'' \times 1''$; $\frac{1}{4}'' \times 2''$.